Weather and UAS Traffic Management (UTM) Workshop
NASA Ames Conference Center
Moffett Field, CA
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MQ-8 (Fire Scout) Icing Impact / Challenges

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MQ-8 (Fire Scout) Icing Impact / Challenges

AGENDA

- Why is Icing CRITICAL?
- Icing Solutions Options / Challenges
- Fire Scout Program / System Background
- Fire Scout Icing Trade Study
- Fire Scout Icing Solutions ROADMAP
- Summary

MQ-8 (Fire Scout) Icing Impact / Challenges

Why is Icing CRITICAL?

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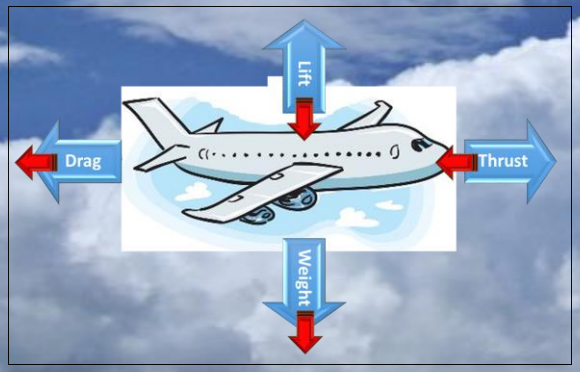
Unmanned AV

Rotary Wing

Fixed Wing



More Complex Phenomenon:

- Variable airspeed along the span,
- Variable blade angle of attack,
- Variable surface temp along the span,
- Smaller airfoil thicknesses / LE radii

Other potential hazards:

- Excessive vibrations and/or critical components failures (asymmetrical ice-shedding from rotor blades)
- Foreign Object Damage (FOD) to other critical components (ice-shedding from rotor blades)
- Loss of directional control (RPM decay)
- Serious deterioration in autorotation performance

Lack of onboard cues:

- Visual Indications
- Changes in AV flight characteristics

Delayed AVO notification

- Significant performance degradation with potential AV loss

MQ-8 (Fire Scout) Icing Impact / Challenges

Potential Safeguards

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Pre-encounter → **Icing**

Avoidance

- Situational Awareness (SA)
  - Weather reports
  - Ice Detection
- Standard Operating Procedure (SOP)
  - Mission Planning
  - Min. Separation
  - Flight ABORTS

Potential Operational Limitations

AND / OR

Ice Protection Capabilities

- Anti- Icing (AI)
  - Engine Inlet
  - Rotor Blades
- De- Icing (DI)
  - Rotor Blades
- Software Solution
  - GNC Algorithm

Design Trade-offs (weight/cost etc.)

IF CRITICAL LIMITS ARE REACHED

Standard Operating Procedure (SOP) → Pilot / AVO AV Evasive Action

MQ-8 (Fire Scout) Icing Impact / Challenges

Ice Protection Systems (Anti / De-icing)

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ACTIVE IPS

Thermal
- Electro-thermal
- Hot Air (Engine Bleed Air)
- Carbon nanotubes

Mechanical
- Pneumatic boots
- Electro-Impulsive

Chemical
- Fluid (Glycol)

Hybrid
- Combination of multiple systems

PASSIVE IPS

Coatings
- Icephobic

Still in development-
- Durability (Erosion)
- Ease of Application

Due to limited SWaP there is a need to develop IPS suitable for lightweight UAVs

MQ-8 (Fire Scout) Icing Impact / Challenges

Ice Detection Systems

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Pre-encounter → **Icing**

Radar –
- Polarimetry
- Multi-frequency (differential attenuation)
- Doppler Spectra

LIDAR –
- Single / Multiple scattering
- Depolarization

Radiometer –
- Microwave sounders
- Polarization
- Multiple frequency

Model-based Estimation Algorithm

What?
- Ice accretion rate
- Ice thickness
- Liquid water content
- Ice water content
- Droplet size
- ….
- ….

Mechanical –
- Vibratory probe

Optical –
- Change in reflective / refractive properties

NO Ice Detection System suitable for lightweight UAVs is yet available that meets SWaP LIMITATIONS and provides adequate ADVANCE NOTIFICATION

MQ-8 (Fire Scout) Icing Impact / Challenges

System Description

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Fully Autonomous Aircraft

Airframe

- Fully Digital, Dual Redundant Control System and C^2 links

MQ-8B MQ-8C

Operational Payloads

- **Open System Architecture facilities integration and testing**

BriteStar II EO/IR/LR/LD

AIS

TACISR / Vortex

Payloads in Test Phase

- **COBRA**
- **Radar (Maritime Surface Search/SAR)**
- **Weapons**

Encrypted, Digital Data Links; Land & Sea Ops

Tactical Control Data Link (TCDL)

UCARS-V2 for Ship Launch/Recovery

Control Station with Tactical Control System (TCS) software integrated

- **Open Architecture**
- **GCCS-M, JDISS, AFATDS, CCTV & JSIPS-N**
- **NATO STANAG 4586 Compliant**
- **Multi-Vehicle control**

Mission Control System (MCS)

MQ-8 (Fire Scout) Icing Impact / Challenges

Program Summary / Current Activities

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MQ-8 Support to Small Surface Combatants

Support LCS Missions in Conjunction with MH-60

- LCS-1 Dynamic Interface (DI) testing on LCS-1, LCS-3, and LCS-4
- COBRA MCM Capability land testing (Apr 2013)
- LCS-3 Deployment (1QFY15)

Maritime ISR Support to SOF (MQ-8B)

- MQ-8B 10th FFG deployment ongoing aboard USS Simpson

Radar

- Provides wide-area maritime search capability
- QRA 2QFY15

Weapons

- Flying qualities testing
- Safe Separation shots
- Land-based QRA (2013) - 12 APKWS shots
- LCS testing still required

Coast Guard

- Demonstration of MQ-8B on WMSL 750 (Dec 2014)

MQ-8B has flown over 16,000 flight hours since 2006
MQ-8C has flown over 750 flight hours since 2013

MQ-8 (Fire Scout) Icing Impact / Challenges

MQ-8B vs MQ-8C

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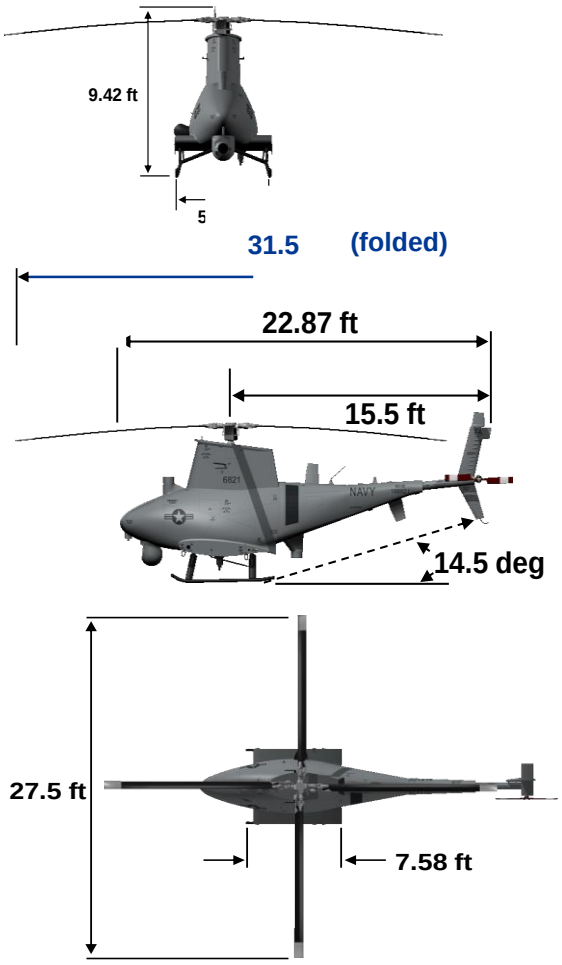
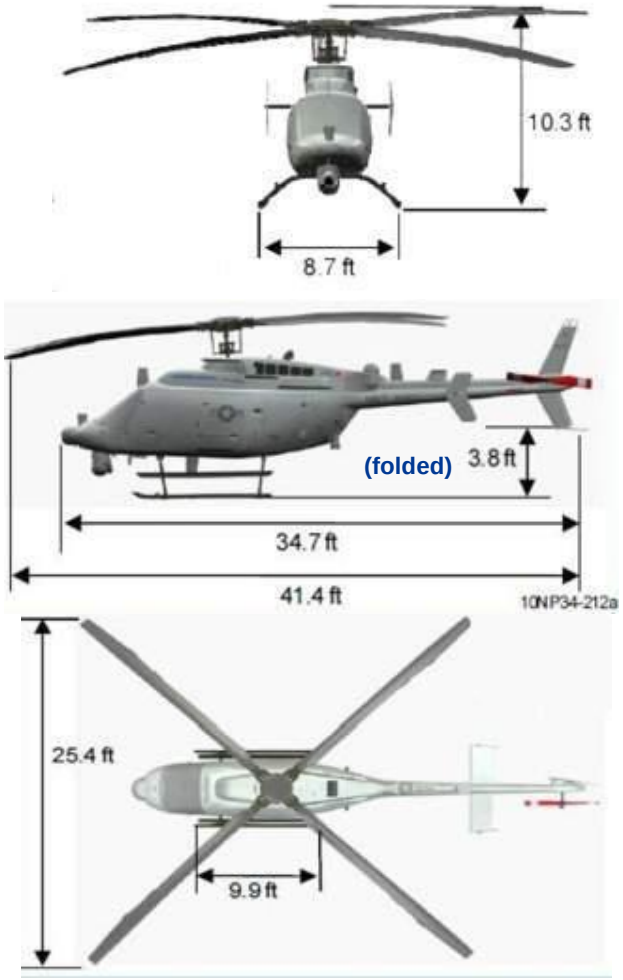


MQ-8B	Parameter	MQ-8C
85 kts	Maximum Speed	135 kts
80 kts	Cruise Speed	115 kts
12,500 ft	Service Ceiling	16,000 ft
5.5 hrs	Std Day Maximum Endurance (with 300lb payload)	12 hrs
4.5 hrs	Hot Day Maximum Endurance (with 300lb payload)	10 hrs
2,000 lbs	Empty Weight	3,200 lbs
3,150 lbs	Std Day Fuel & Payload	6,000 lbs
31.5 ft	Length (folded)	34.7 ft



MQ-8C: 3 ft Longer (folded), 1 ft Taller, 2.5 ft Wider

MQ-8 (Fire Scout) Icing Impact / Challenges

MQ-8 System Commonality

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Common Equipment

- ARC-210 Radios
- Flight Power Conditioning Unit
- Aux Power Conditioning Unit
- Ethernet Switch & Router
- Payload Interface Unit
- Vehicle Management Computers (2)
- Flight Control / Engine Actuators (6)
- Voice Digitizing Module
- Engine Interface Unit
- EO/IR Payload
- Ground Control Panel
- I/O Data Panel
- 3 UHF/VHF Antennas
- 1 UCARS Antenna
- 2 GPS/INS Antennas
- 2 RADALT Antennas
- 2 IFF Antennas

MQ-8B
Schweitzer 333

MQ-8C
Bell 407

Common Equipment

- ARC-210 Radios
- Flight Power Conditioning Unit
- Aux Power Conditioning Unit
- Ethernet Switch & Router
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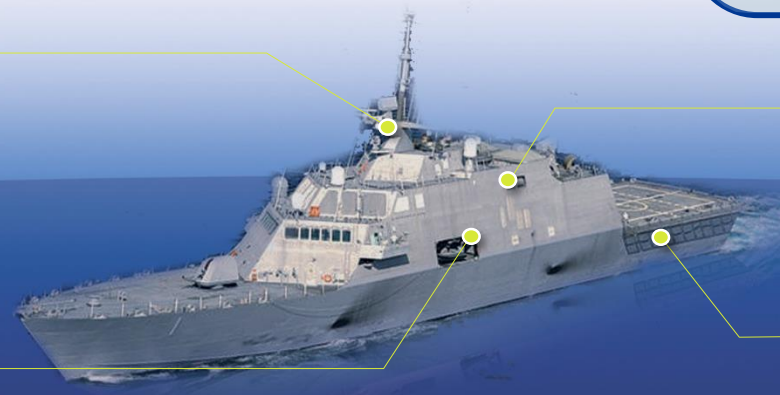
- I/O Data Panel
- 3 UHF/VHF Antennas
- 1 UCARS Antenna
- 2 GPS/INS Antennas
- 2 RADALT Antennas
- 2 IFF Antennas

MQ-8C Unique Equipment

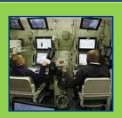
- GPS/INS
- Vibration Monitoring System
- IFF (APX-123)
- TCDL
- RADALT

90% Common Software

TCDL
- Wide band data link
- Component of LCS
- Added for other ship classes



UCARS
- Guidance, Nav, & Control
- Precision Nav



Ship Control Station

TCS

Support Segment
- Deck Handling
- Refuel/Defuel
- Non-powered A/C movement
- Landing Grid

MQ-8B and MQ-8C employ common equipment to the maximum extent possible on both the AV and the Ship with over 90% common software

MQ-8 (Fire Scout) Icing Impact / Challenges
Current Safeguards / CONOPS / Status in Icing Ops

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Ice Detector and Accretion System
- Vibrating probe to detect icing

Engine Anti-Icing
- Compressor bleed air

Pitot System Anti-Icing
- Heated pitot-static system

BRITE Star II EO/IR Sensor
- May be used to see and avoid areas of visible moisture (clouds)

Warning, Caution, and Advisory (WCA)

Avoid Operations in Known / Forecasted Icing Conditions
- Required to maintain certain Horizontal Separation
- Required to maintain certain Vertical Separation

- Frequent delays, altered routes, or cancelled sorties during winter
- To-date there have been two significant in-flight icing events

MQ-8 (Fire Scout) Icing Impact / Challenges
Benchmarking- with Other NAVY UASs

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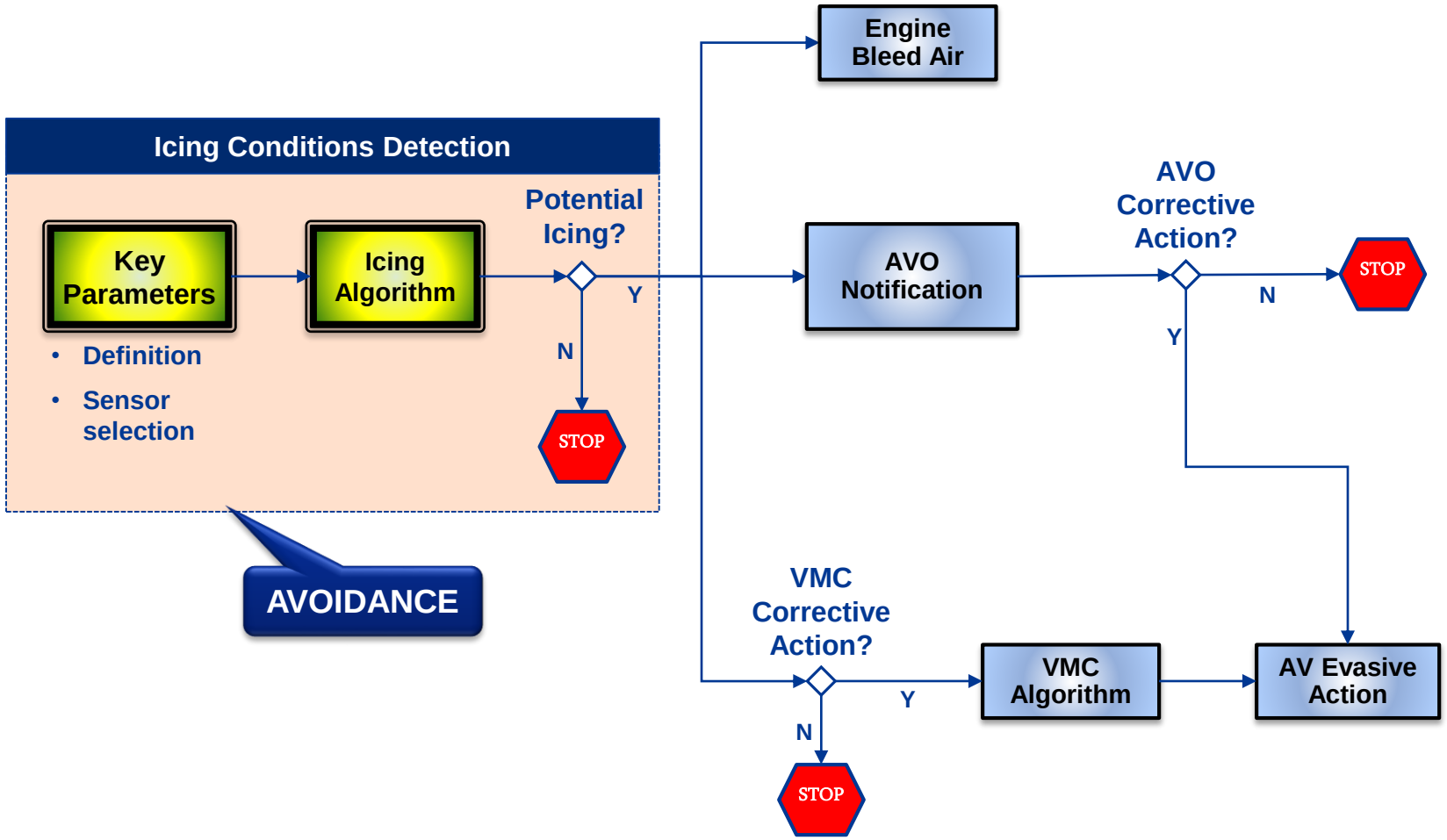
UAS	Group	Ice Protection	Ice Detection	CONOPS	Misc / Comments
Wasp IV	1	None	None	Avoid flights in known/forecast icing conditions	Susceptible to icing if encountered
Raven B					
Puma					
Scan Eagle	2	None	None	Avoid flights in known/forecast icing conditions	Susceptible to icing if encountered
Aerosande					
Shadow	3	None	None	Avoid flights in known/forecast icing conditions	Susceptible to icing if encountered
RQ-21A Blackjack					
Fire Scout (MQ-8B & MQ-8C)	4	-Rotor : None -Engine: Bleed air -Pitot : Electro-thermal	Airframe mounted ice detection probe for in-situ ice detection	Operations in known / forecast icing prohibited	-GNC Logic for evasion -EO/IR for AVO SA -In-flgiht replanning
Cargo UAS (CQ-24a K-MAX)		-Rotor : None -Engine: Bleed Air -Pitot : Electro-thermal	Airframe mounted ice detection probe for in-situ ice detection	Operations in known / forecast icing prohibited	-In-flight replanning
X47B (Demo)	5	None	None	Avoid flights in known/forecast icing conditions	-Demo AV
BAMS-D		None	Airframe mounted ice detection probe for in-situ ice detection	Operations in known / forecast icing prohibited	-In-flight replanning

Most UASs opt for "AVOIDANCE" with limited Ice Protection due to excessive SWaP requirements

MQ-8 (Fire Scout) Icing Impact / Challenges

Fire Scout – Icing Solutions Trade Study



Primary Focus of the Trade Study- Potential Solutions for AVOIDANCE

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study - Process

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1.	**Review the current CONOPS in icing environment**	**Gaps / Limitations**
2.	**Identify key attributes of the Ice Detection System**	**Constraints / Guidelines**
3.	**Prioritize key attributes using appropriate weighting factors**	**Comparative Assessment**
4.	**Identify potential solutions**	**RFI**
5.	**Map each solution against key system attributes -** ▪ Type of technology, ▪ Technology readiness level, ▪ Ease of implementation, ▪ Cost / schedule for implementation ▪ ….	**Vendor Information**
6.	**Prioritize solutions based on (weighted) key attributes**	**C & A Matrix**
7.	**Develop Roadmap**	**Deliverable**

Trade Study Process utilizes a Systems Engineering Approach

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Prioritized Key Attributes

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Weighting Factor	Key Attribute	Threshold (if any)
10	Adverse Weather Performance (Low visibility, day/night, near all weather)	
9	Accuracy (High probability of detection, Low false alarm)	
9	Range (Detection range, azimuth, elevation)	5 nmiles
8	Operational Availability / Reliability / Maintainability	
7	Emission Control	
7	Ease of Integration (Cost / Schedule)	
6	Technology Readiness Level	
5	Shipboard Components & Mods Required	
5	AV Mods Required / Impacts (SWaPC)	
4	Time to notify AVO (update rate, processing time, latency, etc.)	
3	Spoofing / Jamming Susceptibility	
3	Compatibility with both broad/narrow band data links	
2	Denied GPS Functionality	
1	Commonality (‘B’ & ‘C’)	

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – RFI / Vendor Proposals

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MQ-8 (Fire Scout) Icing Conditions Detection Capability

Request for Information (RFI)

Detailed Requirements Attachment

7/31/2014

******THIS RFI IS FOR INFORMATION OR PLANNING PURPOSES ONLY******

Contracting Office Address: Department of the Navy, Naval Air Systems Command, AIR 2.4.2.1, Bldg 441, 21983 Bundy Patuxent River, MD 20670-1547

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22707 Cedar Point RD
Building 3261
Patuxent River, MD 20670

Phone Number: (301) 757-6403

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VENDORS
OPTION 1
OPTION 2
OPTION 3
OPTION 4
OPTION 5
OPTION 6
OPTION 7
OPTION 8
OPTION 9
OPTION 10
OPTION 11
OPTION 12

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Mapping Vendor Proposals

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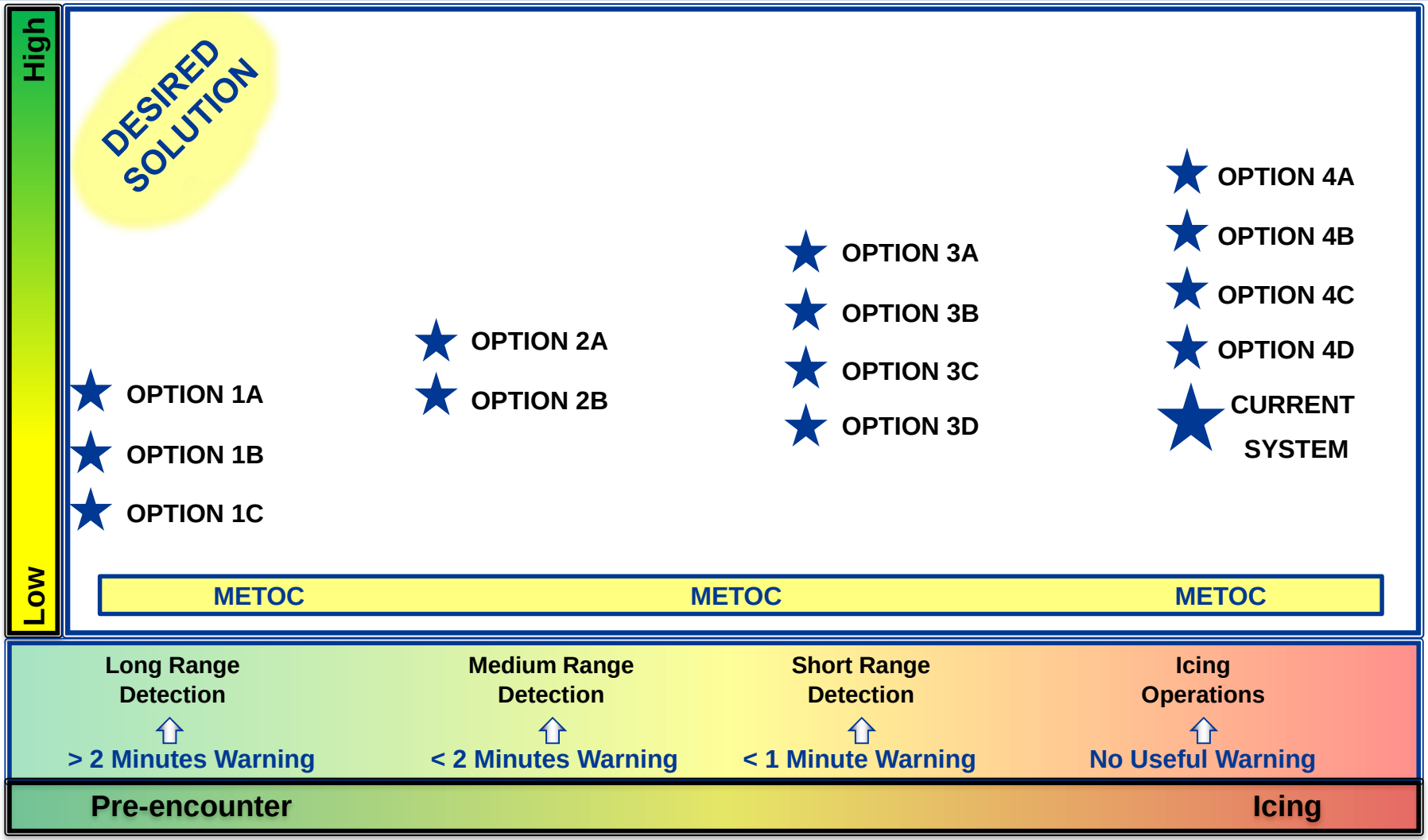

NO ONE PROPOSAL PROVIDES THE DESIRED SOLUTION

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Systems of Systems Approach

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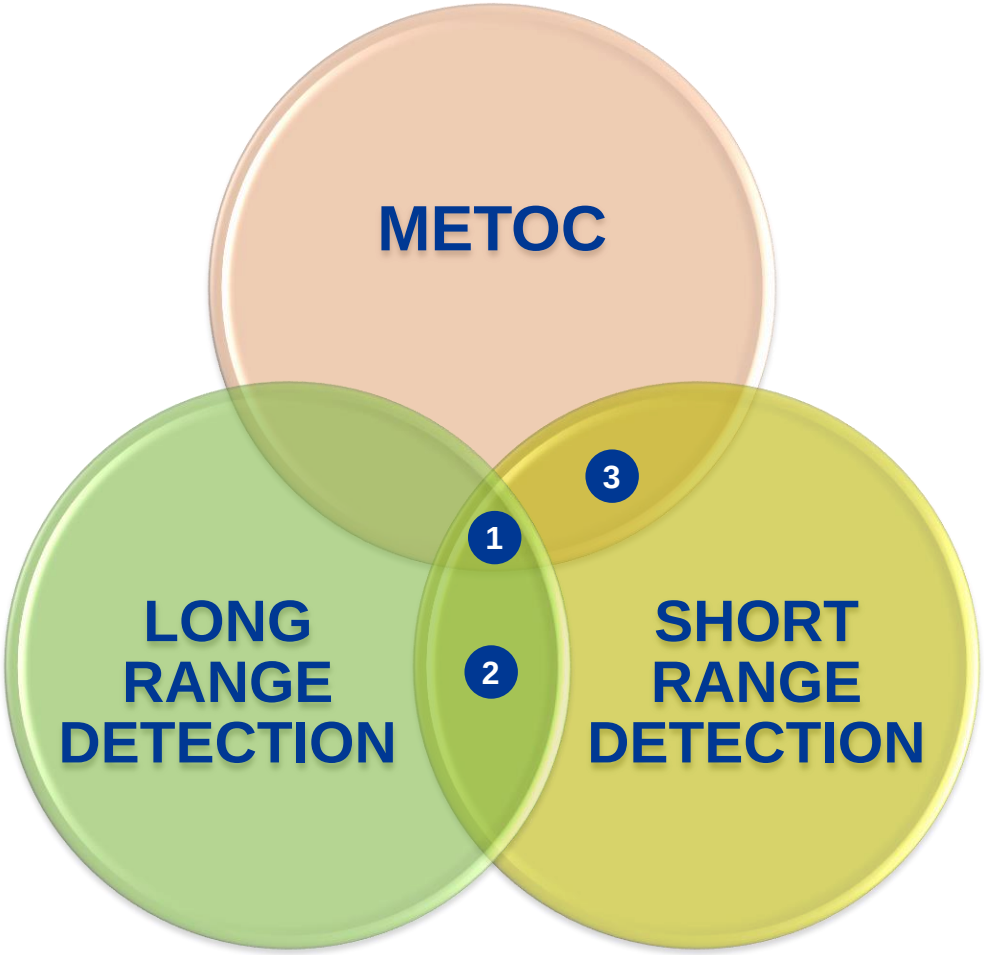

1 METOC info for general SA
Long Range Detection
Short Range Detection

2 Long Range Detection
Short Range Detection

3 METOC info for general SA
Short Range Detection

NO ONE PROPOSAL PROVIDES THE DESIRED SOLUTION

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Cause & Effect Matrix (Prioritization)

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	Rating of Importance to Client (Rank 1-10)	10	9	9	8	7	7	6	5	5	3	3	2	2	1			
	Metric No.	1	2	3	4	5	6	7	8	9	11	8	9	10	11			
	Process Outputs (Big Y's) / High-Level Processes (Rank 0, 1, 3, 7, 9)	Adverse Weather Perf	Accuracy	Range	Operational Avail / Rel / Maint	Emission Control	Ease of Integration (Cost/Schedule)	TRL (Maturity)	Shipboard Components & Mods	AV Components & Mods (SWaPC)	Spoofing/Jamming Susceptibility	Time to notify AVO	Compatibility with broad/narrow band datalinks	Denied GPS Functionality	Commonality (MQ-8B and MQ-8C)	Total (Weighted Score)	Ranking	Device Type
1	OPTION 4A																1	1
2	OPTION 4B																2	1
3	OPTION 4C																3	1
10	OPTION 4D																10	1
5	OPTION 3A																5	2
6	OPTION 3B																6	2
11	OPTION 3C																11	2
13	OPTION 3D																13	2
9	OPTION 2A																9	3
12	OPTION 2B																12	3
4	OPTION 1A																4	4
7	OPTION 1B																7	4
8	OPTION 1C																8	4

Surface Contact (0 - 50 meters)

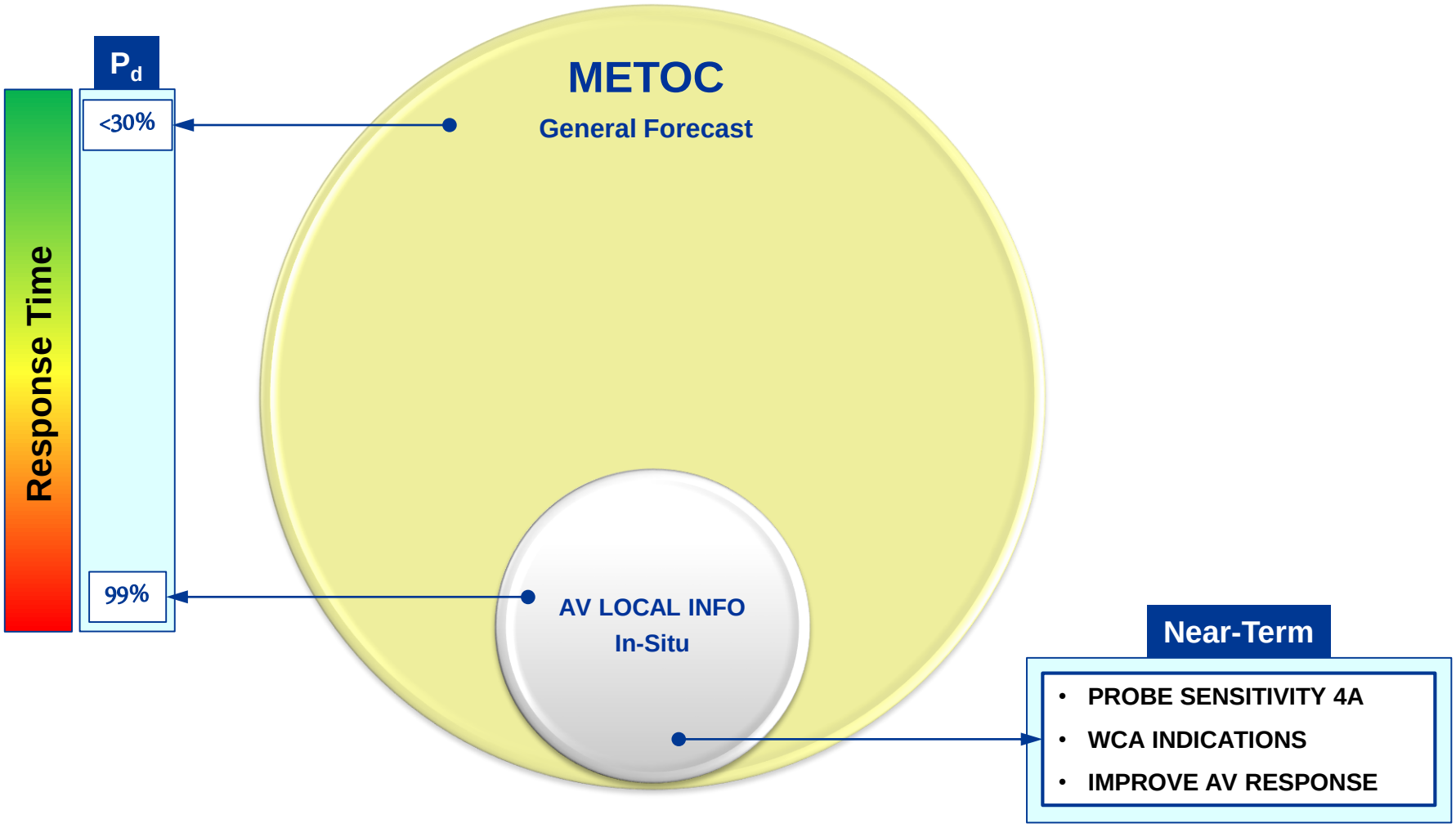
Short Range (< 1 km)

Medium Range (1 - 4 km)

Long Range (> 4 km)

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Roadmap Development Strategy (NT)



MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Roadmap Development Strategy (LT)

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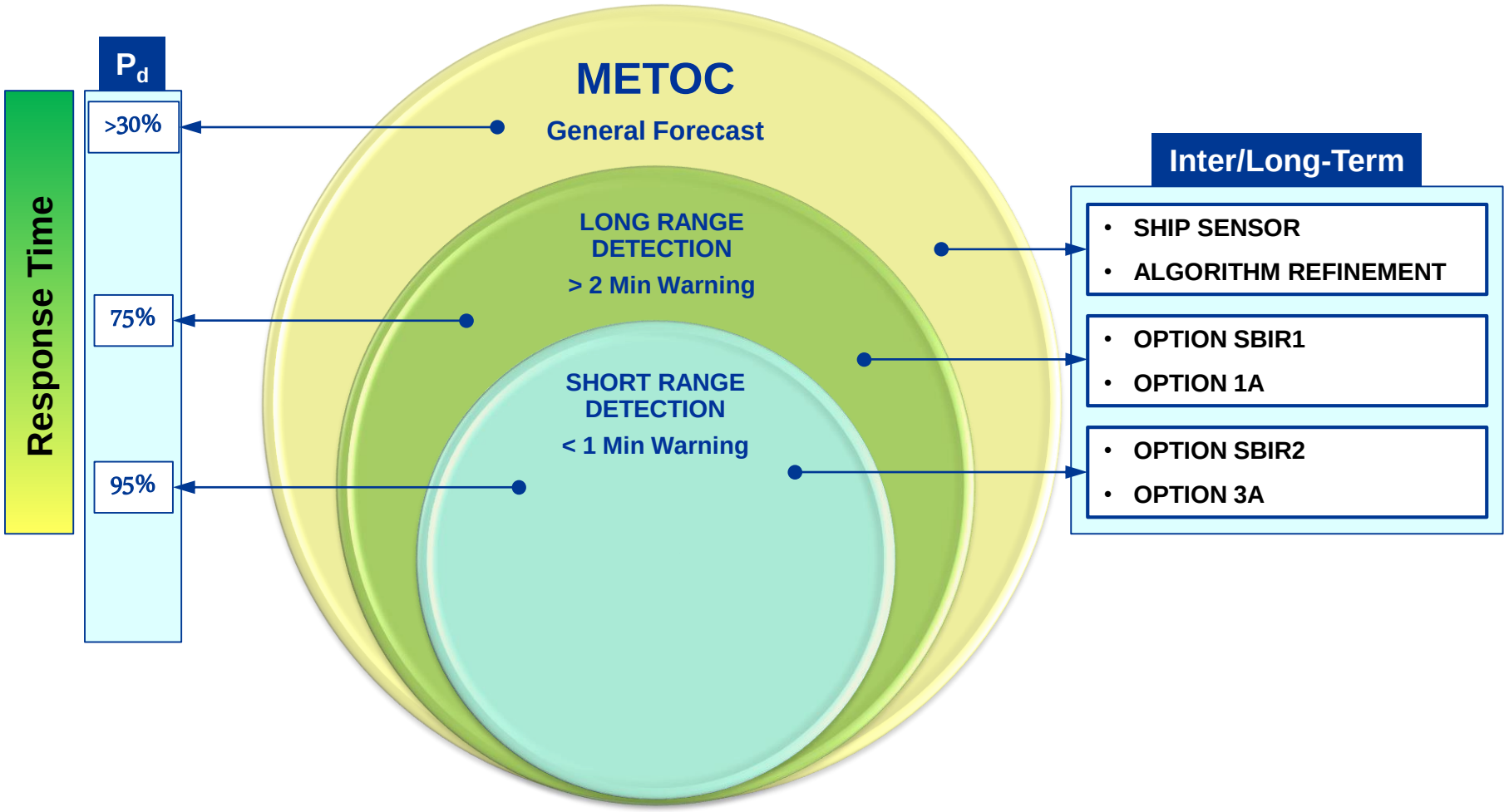

MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Roadmap Dev Strategy (Integrated)

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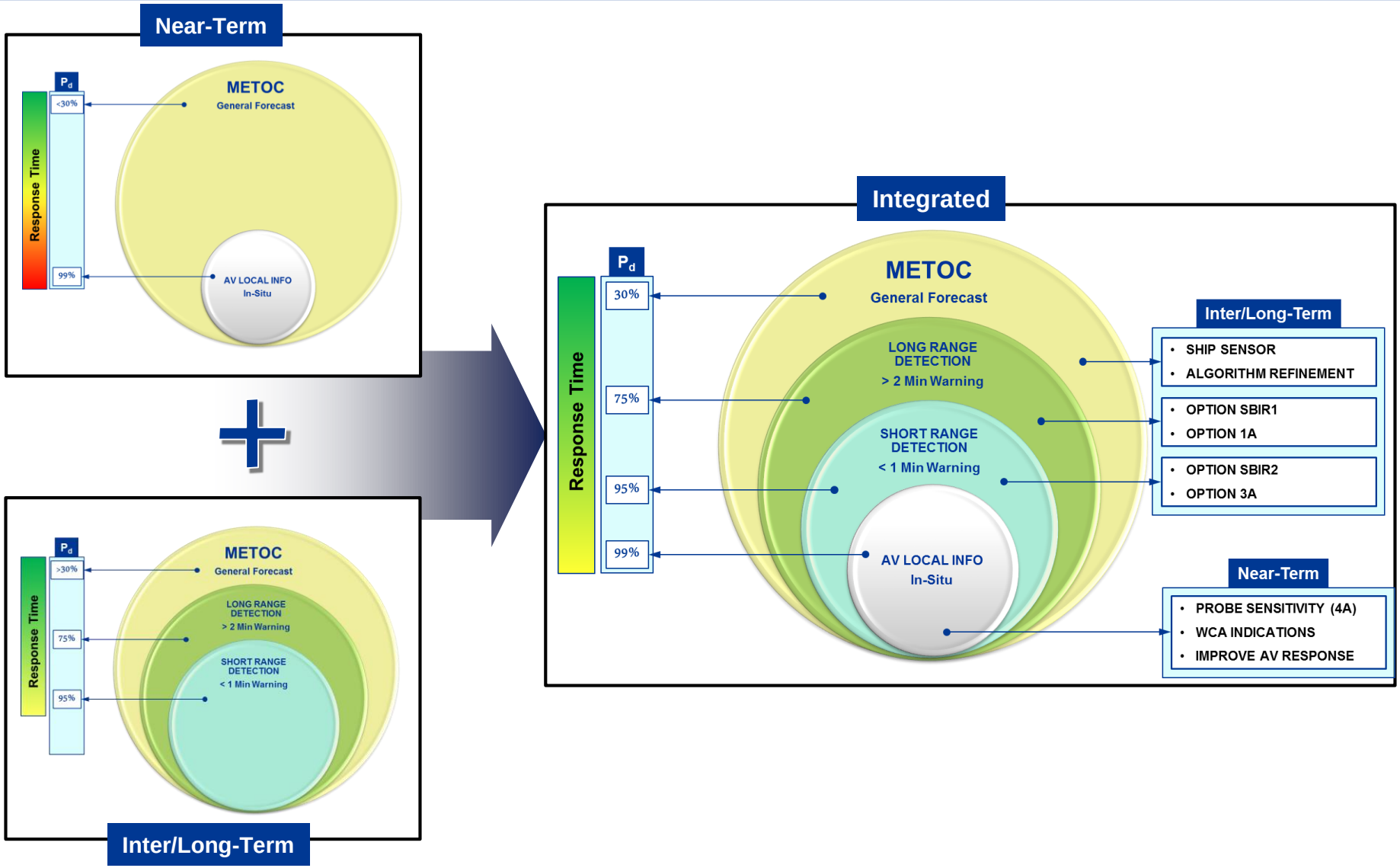
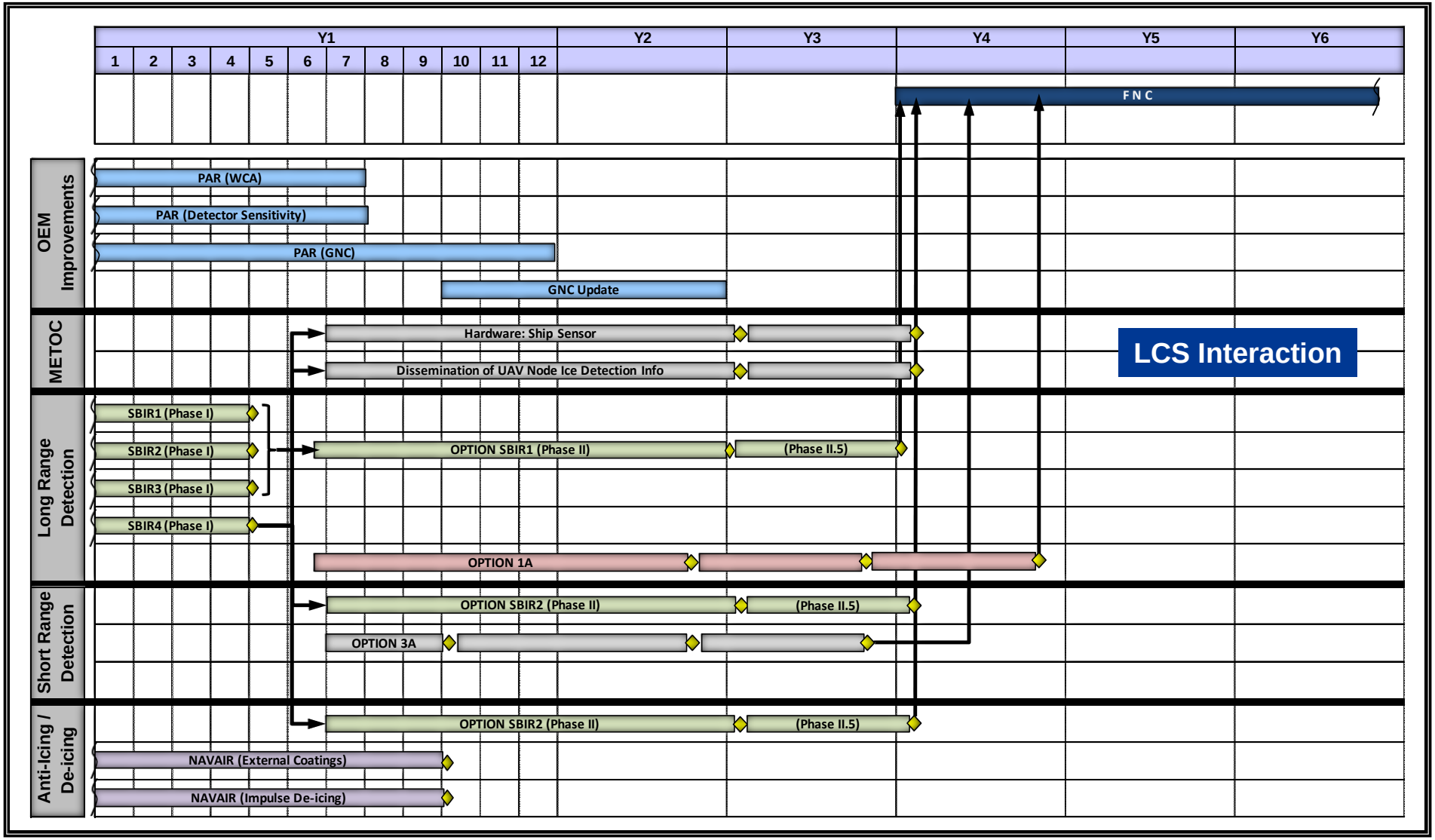


MQ-8 (Fire Scout) Icing Impact / Challenges

Trade Study – Integrated Roadmap



MQ-8 (Fire Scout) Icing Impact / Challenges

SUMMARY

- Fire Scout design has inherent safeguards against icing
- Additional safeguard is provided by current CONOPS limiting operations in known / forecasted icing
- There is a compelling need for an early detection system for providing AVO an advance warning of impending icing condition
- There is NO ONE solution available yet that is suitable for lightweight UAS
- The ready icing solution will involve composite solutions using Systems-of-systems approach
- An Integrated ROADMAP providing near-term and long-term solutions has been developed and implemented


Questions

MQ-8 (Fire Scout) Icing Impact / Challenges

System Overview

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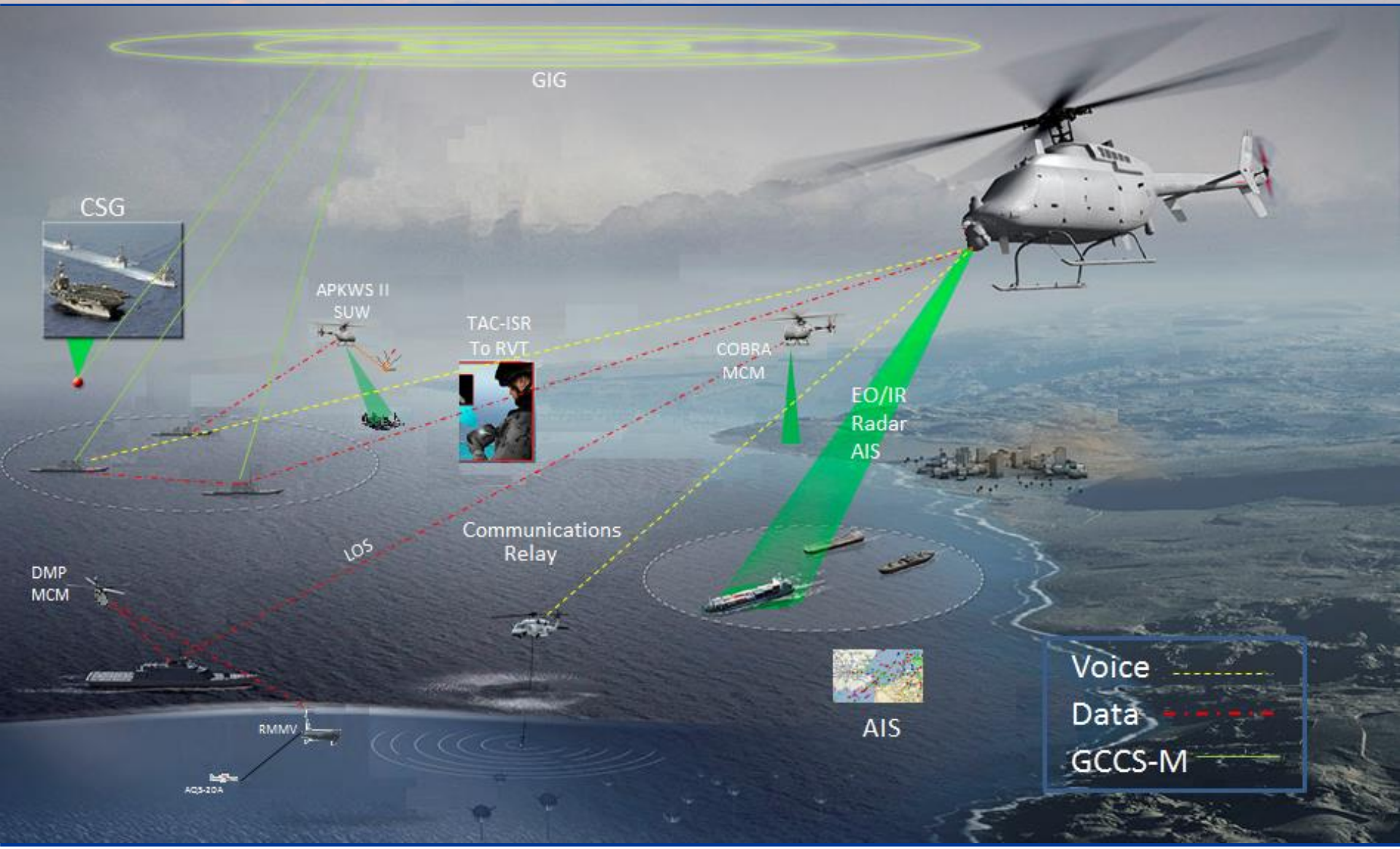

MQ-8 (Fire Scout) Icing Impact / Challenges
Trade Study – Roadmap Development Strategy

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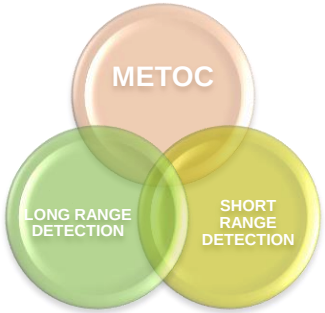
Near-Term Strategy

- Improve Situational Awareness -
  - AV Ice detection probe sensitivity investigation
  - WCA indication to the AVO accompanied by other secondary indications (such as engine N2, TOT, and Nr exceedances)
- Improve AV Response -
  - When the AV gets into icing, ensure that GNC/AVO actions don't accelerate the loss of the aircraft

Intermediate/Long-Term Strategy

- Improve Situational Awareness -
  - Better METOC reporting
  - Early warning of impending icing conditions



- Better sensing-
  - The AV needs the ability to gather its own tactical information about icing to enable the GNC/AVO to take evasive action(s)

MQ-8 (Fire Scout) Icing Impact / Challenges

Detection Range

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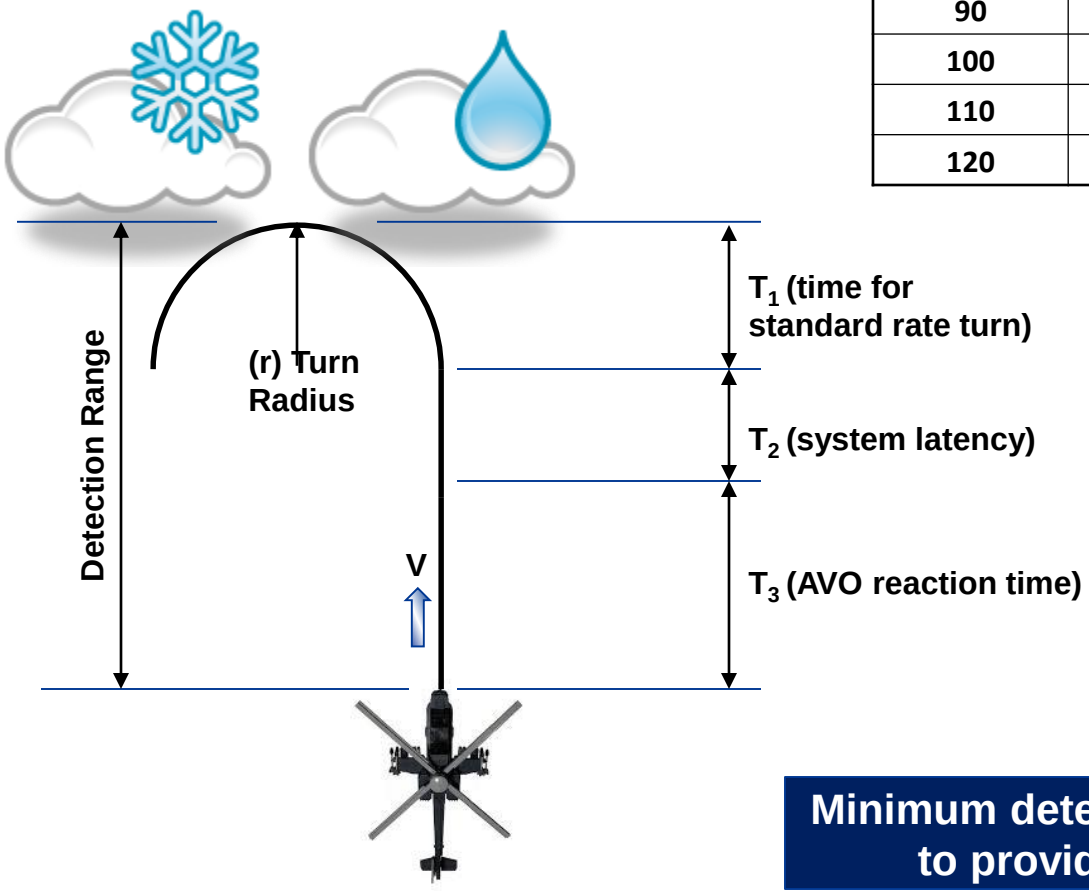
AV Forward speed	Turn radius w std turn	System Latency	AVO reaction time	Detection Range
TAS (Kts)	r (Nmiles)	T_2 (sec)	T_3 (min)	Range (Nmiles)
80	0.42	10	3.3	5.0
90	0.48	10	2.8	5.0
100	0.53	10	2.5	5.0
110	0.58	10	2.2	5.0
120	0.64	10	2.0	5.0



Minimum detection range of 5 nmiles is expected to provide adequate AVO reaction time